A CPW-fed Antenna on 3D Printed EBG Substrate

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***Abstract*— This paper proposes a coplanar waveguide (CPW) fed antenna and electromagnetic band gap (EBG) structure on 3D printed substrates. Low-cost fuse filament fabrication (FFF) technology is employed. Two sets of experiments are described. In the first, the antenna and EBG patterns are etched on copper clad Mylar® polyester film and attached to the 3D printed substrates. In the second, the patterns of the EBG are added using silver conductive paint. Both experiments compare very well between them, and with the simulations. The EBG structure provides improved antenna performance such as gain, efficiency and directivity. The antenna and EBG are designed for the 2.4 GHz Bluetooth frequency band. The Finite-difference time-domain (FDTD) computational method was used for the study.**

Keywords-CPW antenna; EBG structure; 3D printing; silver-loaded conducting ink

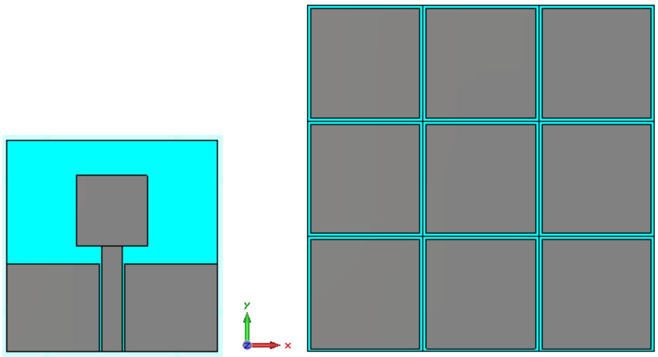


Fig.1 Geometry of CPW antenna and EBG structure (a) CPW-fed antenna (b) EBG structure

I. Introduction

3D printing is a trendy manufacturing process currently used for prototyping and fabrication of customized objects. In these applications, it can save time and costs compared to standard fabrication processes. Fused Filament Modeling (FDM) is the most popular technologies for home 3D printers. It offers the lowest costs for additive manufacturing. Three dimensional objects are created by melting a plastic and then depositing in layers. The dominant materials are polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS). FFF has recently been proposed for the development of novel frequency selective structures (FSS) [1] – [2], and to assist in the fabrication of wearable antennas [3]. In [2], the FSS were fabricated by partially metalising complex 3D printed shapes with silver conductive paint. This technique was able to reduce the size and improve the angle of incidence performance of the FSS compared with the fully metallised design [4].

Electromagnetic Band Gap (EBG) structures have received significant scientific attention in the last two decades [5] – [6]. In their most basic form, they consist of a layer of FSS over a ground plane. They can improve antenna performance and reduce the size of antennas in close proximity to metallic plates [5] – [6]. In [6], for example, a dual-band EBG structure consisting of 3x3 cells was able to improve radiation and reduced SAR for body area networks. There, textile substrates were used for the antenna and EBG structure.

This paper presents a small-size EBG structure and CPW-fed antenna on additive manufactured substrates. FFF with low-cost PLA material is used. The arrangement of the antenna and EBG array follow the techniques described in [5] and [6]. The antenna is placed at a short distance from the EBG and tested. The main aim is to study the use of inexpensive additive manufactures substrates for the development of EBG structures for improved antenna performance. Silver-loaded paint has been used as the conducting material for the FSS layer, and compared with copper etched Mylar® polyester Film substrate. All simulation results have been carried out with CST Microwave studio. This paper is organized as follows: section II introduces the design of the EBG and antenna, section III covers the fabrication and tests, and section IV discusses the results and draws some conclusions.

II. Design of CPW antenna and EBG

The geometry of the antenna and EBG structure is shown in Fig 1 (a) and (b) respectively. The antenna is a planar monopole with a small ground plane. The feeding network consists of a coplanar waveguide (CPW) transmission lines. The EBG array is made up of 3x3 square elements arranged on a square lattice. The substrate considered for the models have the electrical characteristics of white PLA material, with approximate dielectric constant of ($\varepsilon_r = 2.4$), and loss tangent of less than tanδ=0.01 [7].

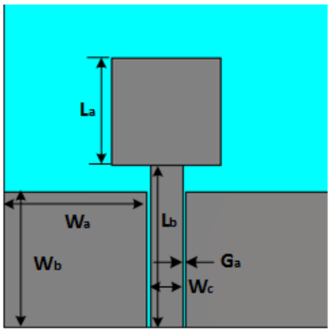


Fig.2 Geometry of CPW antenna

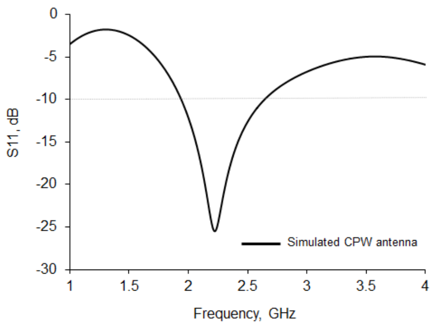


Fig.3 Simulated reflection coefficient (S_{11}) of the antenna in free space

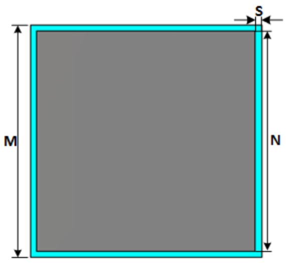


Fig.4 Unit cell of the EBG structure with dimensions

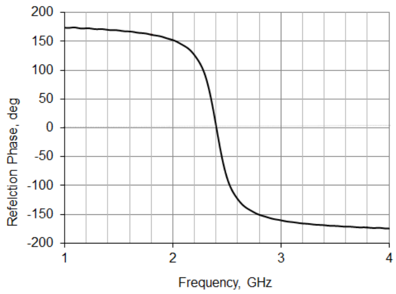


Fig.5 Reflection phase diagram of the EBG structure

The main dimensions of the antenna as given in Fig.2. These are: L_a= 20 mm, L_b= 30 mm, W_a= 26.5 mm, W_b= 25 mm, G_a=0.5 mm, W_c= 6 mm. The overall dimension is 37 mm x 37 mm. The thickness of the dielectric substrate was 2mm.

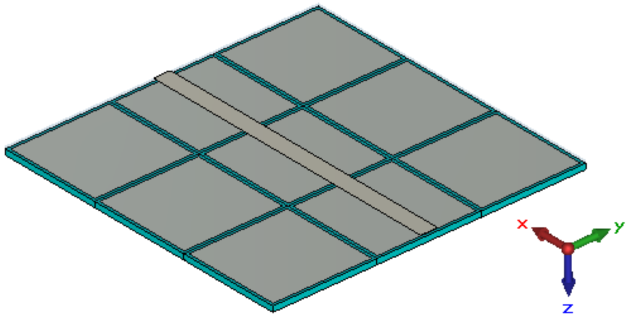


Fig.6 Suspended microstrip line on the EBG structure

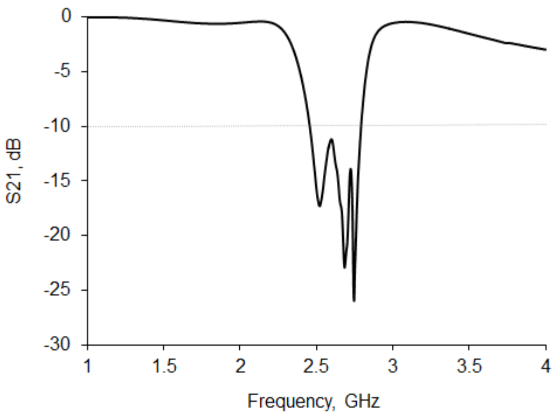


Fig.7 S21 of suspended the microstrip line on the EBG structure

Fig.3 shows the computed reflection coefficient (S_{11}) of the antenna in free space. The S_{11} is less than -10dB from 1.9 to 2.6 GHz with the minimum level at 2.2 GHz.

The EBG consists of 9 square patches (Fig. 1(b) of side N = 35 mm and periodicity M = 37 mm (Fig. 4)). The total dimensions is 111 mm x 111 mm, and thickness of 2mm. No shorting vias are used as it is not necessary for the intended application. As described in [8], the effect of the shorting via on the EBG structure can be neglected.

The computed reflection phase of an infinite number of EBG cells is shown in Fig. 5. It covers the desired resonant frequency of 2.4 GHz with a relative bandwidth of 8.3% for -90 to 90 degrees. After confirming the operation of the infinite design, a second computer simulation was set up according to [9]. A microstrip transmission line was placed at 1mm from the EBG, as illustrated in Fig.6. Two ports connect at the end of left and right side of the suspended line. The transmission coefficient (S_{21}) of this model is shown in Fig.7. Transmission levels of less than -10dB were found from 2.45 to 2.79 GHz, proving the operation of the EBG at about the desired frequency band.

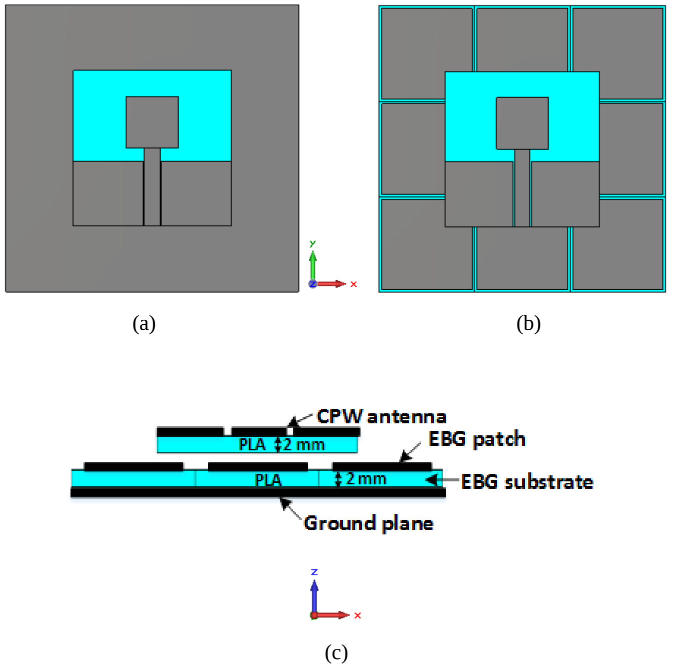


Fig.8 Configuration of CPW antenna on (a) PEC ground (b) EBG structure (c) side view of the antenna and EBG

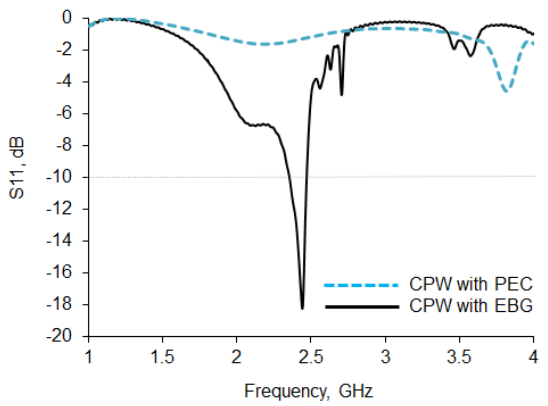


Fig.9 Reflection coefficient (S_{11}) of CPW antenna with PEC ground and EBG structure

Fig 8 shows the combination of the CPW antenna and EBG structure (Fig.8 (b) and (c)), as well as when the antenna is placed on a perfect electric conductor (PEC) (Fig. 8 (a)). The distance between the antenna and the EBG is 1mm. This gap is crucial for the performance of the antenna. The computed reflection coefficient (S_{11}) is shown in Fig. 9. At 2.4GHz, the return loss on the PEC ground is 1.31 dB at 2.4 GHz, whereas a return loss of 18.31 dB is obtained with the EBG structure. The surface current distribution of the combined CPW antenna and EBG structure can be found in Fig 10. There is clear coupling between the antenna and the EBG structure. Currents concentrate mainly on the left and right side of the EBG array.

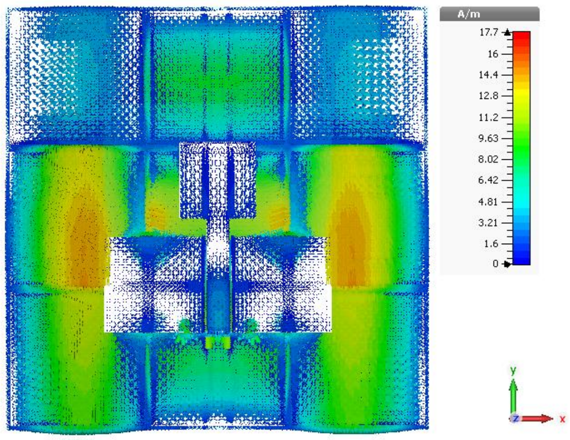


Fig.10 Simulated surface current distribution of the combined CPW antenna and EBG structure at 2.4 GHz

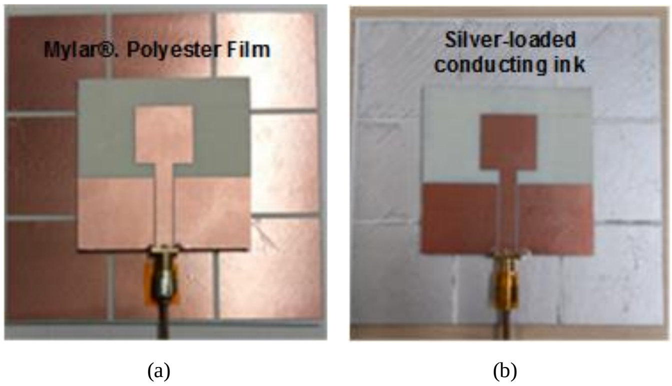


Fig.11 Configuration of CPW antenna with EBG structure (a) etched onto copper clad Mylar, (b) coated using silver-loaded conducting ink

III. Fabrication and Measurements

A. Fabrication

An Ultimaker 3D printer was used to fabricate the CPW and EBG substrates. The .STL models were converted into machine coding using Cura software. The density of the polylactic acid (PLA) substrates was set at 100 %. Two fabrication methods for the EBG structure were studied. In the first one (Fig.11 (a)), the FSS layer was etched on the copper clad of a Mylar® polyester Film substrate of thickness of 0.05 mm and attached to the substrate using double-sided sticky tape. From authors' experience, the thin Mylar substrate has little effect on antenna performance. In the second, the patterns were created by coating the substrate with silver-loaded conducting paint (Fig.11 (b)). A stencil was employed to produce the FSS patterns. In both cases, the antenna and ground planes were etched on the copper clad of a Mylar® polyester Film. A semi rigid coaxial cable with an SMA probe connected the antenna to the test equipment.

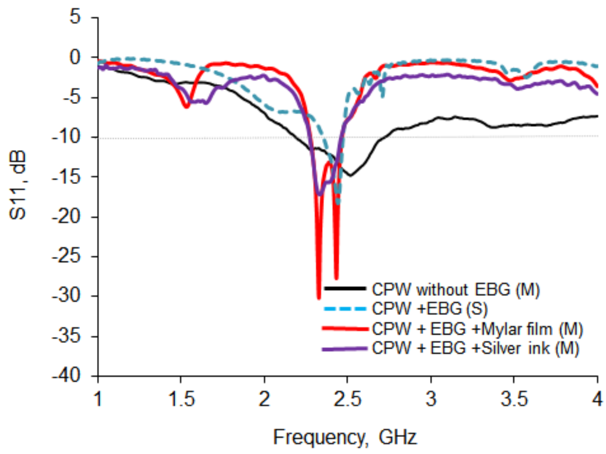


Fig.12 Reflection coefficient (S_{11}) of CPW antenna with EBG structure (S: Simulation, M: Measurement)

B. Antenna performance

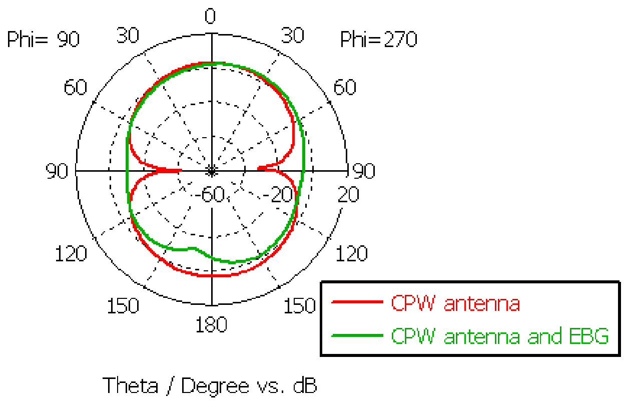
Fig 12 depicts the result of the S_{11} of the antenna in free space, and on the EBG structure. The -10 dB bandwidth in free space, on the copper EBG substrate, and on the silver coated EBG are 520, 190 and 120 MHz respectively. The bandwidth is clearly narrower on the EBG structure. Nevertheless, all results cover the desired 2.4 GHz Bluetooth frequency band. The results for the silver-coated EBG are very similar to those for the copper etched on Mylar®.

Fig 13 compares the simulated radiation patterns of the antenna in free space, and on the EBG array. In free space, dipole-like omni-directional radiation pattern is observed in the yz plane. The gain of the antenna on the EBG structure in the H plane increases from 2.57 dB to 6.98 dB. The back radiation is reduced. The total radiation efficiency improves by 7.28 %.

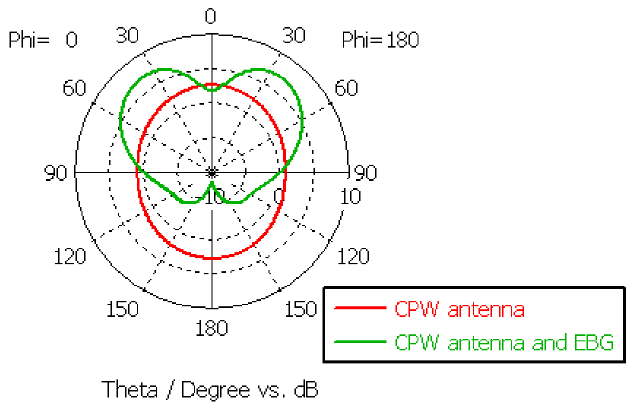
IV. CONCLUSION

The applicability of inexpensive additive manufacturing technologies to the development of EBG substrates for antenna applications has been demonstrated. Low-cost materials such as PLA are suitable for this purpose. The use of metallic paint for the EBG compares very well with more commonly used subtractive methods. More specifically, results are similar to those etching the patterns on copper clad Mylar Polyester films. The differences between simulations and test results are due to manufacturing and measurement tolerances. The 3D printed substrates were not exactly uniform. The semi rigid coaxial cable with the SMA connector also affected results.

In this demonstrator, the metallic paint was applied manually but other additive methods such as the one described in [10] could be used. Polyester Films have limitation in realizing antenna and EBG with complex 3D shapes. This limitations can be overcame using 3D printed substrates. This is will be explore in future work.



(a)



(b)

Fig.13 Simulated radiation pattern at 2.4 GHz (a) E plane (YZ plane) (b) H plane (XZ plane)

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